

Title of the Grant

Cluster II Wideband (WBD) Plasma Wave
Investigation Mission Operations and Data
Analysis

Type of Report

Summary of Research

Name of the Principal Investigator

Donald A. Gurnett

Period Covered by the Report

October 1, 2000 through January 14, 2004

**Name and Address of the
Recipient's Institution**

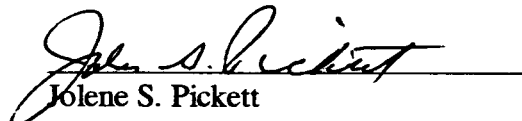
The University of Iowa
Sponsored Programs
100 Gilmore Hall, Room 2
Iowa City, IA 52242

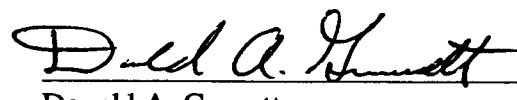
Grant Number

NAG5-9974

Signature

Prepared by:


Jolene S. Pickett
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Donald A. Gurnett
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SUMMARY OF RESEARCH

1.0 Purpose

This Summary of Research is being submitted to NASA Goddard Space Flight Center in fulfillment of the final reporting requirement under Grant NAG5-9974. The following contains a summary of the significant accomplishments of the Cluster Wideband (WBD) Plasma Wave Investigation team achieved during the period of the grant, October 1, 2000 through January 14, 2004, and a listing of all of the publications that resulted from work carried out under the grant. Also included below is a listing of the numerous public outreach activities that took place during the period of the grant in which the Cluster mission and Cluster WBD science were discussed.

2.0 Summary of Significant Accomplishments

Chorus: One of the most exciting and prolific areas of research by the Cluster WBD science team has been that of whistler mode chorus waves observed in the inner magnetosphere. The multi-spacecraft aspect of Cluster has led to many new results in this area. The first totally unexpected result reported by Gurnett et al. [2001] was that correlated chorus elements had significant frequency variations (~ 1 kHz), indicating that the frequency of the wave packets may be evolving as the wave propagates. Inan et al. [2004 in press] did a follow up study on this aspect of the chorus, interpreting this frequency difference as a natural outcome of the dependence of the whistler-mode refractive index on the wave normal angle between the wave vector k and the static magnetic field B_0 and the rapid motion of highly localized source region(s) of chorus of 400 km to 1700 km in extent along the field line, but only less than 100 km transverse to the magnetic field, and moving at speeds of 20,000 km/s to 25,000 km/s. Chorus wave packets emanating from the localized regions propagate to two spacecraft at different frequencies due to the differential Doppler shift between the two spacecraft. Inan et al. [2004 in press] used these frequency differences to study the motion of the sources. Their results provide the first experimental evidence that the sources that generate the discrete chorus emissions are in rapid motion.

Santolik and Gurnett [2003] and Santolik et al. [2003] have carried several studies of storm-time (geomagnetically disturbed period) chorus using the multi-spacecraft data provided by the Cluster WBD receiver. The initial study [Santolik and Gurnett, 2003] focused on the generation region where they found that cross-spacecraft correlation for storm-time chorus is significant throughout the range of separation distances of 60-260 km parallel to the field line and 7-100 km in the perpendicular plane. The fine structure of the storm-time chorus was examined in detail in Santolik et al. [2003], where they found that the chorus wave packets, appearing as rising discrete elements on the power spectrograms, have an internal fine structure consisting of separate subpackets of variable lengths up to 40 ms. These subpackets seem to appear in the waveform in a random way without any clear periodicity. They also found that at the start of the majority of these subpackets there is an exponential growth phase which could be consistent with a linear instability or with the linear growth of the triggered emissions. Finally, they found that simultaneous observations on the four Cluster spacecraft show that even if chorus elements are well correlated on the power spectrograms at time scales of 0.1 s, their internal subpacket structure is different on the different spacecraft. This either means that the fine structure has a shorter characteristic dimension than a few tens of kilometers in the plane perpendicular to the ambient magnetic field or else the fine structure changes along the field line at spatial scales of hundred of kilometers.

Auroral Kilometric Radiation: The multi-spacecraft aspect of Cluster has allowed for the first time ever the use of the Very Long Baseline Interferometry (VLBI) technique for determining locations of auroral kilometric radiation (AKR). This technique involves cross-correlating individual AKR bursts by using time and frequency-filtered waveforms from the Cluster WBD instrument located on all four of the Cluster satellites providing six unique baselines. Mutel et al. [2003] used the Cluster data and VLBI technique to determine the locations of more than 1700 AKR bursts above the northern and southern polar regions during six epochs between July 2002 and January 2003. They found that for the Northern Hemisphere, the AKR source locations favored the local evening sector, indicating that the AKR locations are located along magnetic field lines connecting the statistical auroral oval and are in good agreement with previous AKR location studies. For the Southern Hemisphere, the AKR source locations had mean magnetic local times close to midnight or in the morning sector and magnetic latitudes somewhat poleward of the statistical auroral oval. Mutel et al. [2003] also found that on timescales of 1-3 hours the locus of AKR footprint locations in the auroral zone had a characteristic spatial scale between 1000 and 4000 km, significantly larger than the uncertainty in the AKR burst location magnetic footprint. Finally, for two of the epochs, Mutel et al. [2003] found a significant drift in the mean location of AKR activity over a period of 1-2 hours. The drift was predominantly in latitude at one epoch and in longitude at the other, with average drift speed $V \sim 80\text{--}90 \text{ m s}^{-1}$ at the AKR emission location.

Solitary waves: The WBD receivers on the four Cluster spacecraft are providing the first comprehensive measurements of solitary waves (positive potential structures known as electron phase-space holes) observed in the magnetosheath. These solitary waves, observed in the WBD waveforms as bipolar (one positive peak followed by one negative peak, or vice versa) pulses, are of very short time duration, $\sim 25\text{--}100 \mu\text{s}$ [Pickett et al., 2003]. Solitary waves with such short time durations have only been observed in the auroral acceleration region. Pickett et al. [2003] showed that in the magnetosheath these solitary waves when observed over long periods of time (hours) with spacecraft separations as large as 750 km and their waveforms converted to the frequency domain by means of Fast Fourier Transform have amazingly similar frequency extent, intensity, and onset and termination times. This suggests that the generation region of the solitary waves is large and perhaps tied to the bow shock. Another multi-spacecraft study of solitary waves, observed in the auroral zone at $4.5\text{--}6.5 R_E$, was carried out by Pickett et al. [2004 in press]. They report the first major observations of tripolar pulses (two positive peaks with an intervening negative peak, or vice versa) along with the bipolar pulses. The tripolar pulses are believed to be weak double layers since there is a measurable potential change across them. A cross correlation study of the solitary waves in the auroral zone led to the conclusion that the spacecraft, at even short separation distances of $\sim 100 \text{ km}$ was too great to observe one solitary wave of the bipolar pulse type propagate from one spacecraft to the next, probably due to decay or evolution to some other form. Limited success at correlating the tripolar pulses led to the conclusion by Pickett et al. [2004 in press] that the tripolar pulses were propagating along magnetic field lines at several hundred to a few thousand km/s with sizes on the order of $2\text{--}5 \text{ km}$ parallel to B and $25\text{--}60 \text{ km}$ cross B . Solitary waves most likely play a role in the overall dynamics of boundaries and acceleration regions of Earth, a topic that will be addressed in future studies.

HAARP/Cluster Conjunction Studies: Several joint experiments were carried out using the four Cluster spacecraft and the high power HF heater at Gakona, Alaska, known as HAARP (High Frequency Active Auroral Research Program). When the Cluster spacecraft are in the northern hemisphere on magnetic field lines whose footprint is within $\sim 500 \text{ km}$ of the HAARP facility, the HAARP HF heater modulates the auroral electrojet currents overhead at a series of fixed ELF/VLF frequencies. The modulated currents radiate Electromagnetic (EM) waves which propagate through the ionosphere and enter the magnetosphere, where they are observed on Cluster at altitudes $\geq 20,000 \text{ km}$. These experiments have led to an unexpected result by Bell et al. [2004 in press], i.e., strong excitation of lower hybrid (LH) waves by the radiated EM whistler mode waves, produced by the HAARP modulated currents, outside the

plasmasphere. Previous observations of this phenomenon occurred at altitudes ≤ 7000 km. According to Bell et al. [2004 in press] the excitation mechanism appears to be linear mode coupling in the presence of small scale plasma density irregularities. The observations provide strong evidence that EM whistler mode waves are continuously transforming into LH waves as the whistler mode waves propagate at high altitudes beyond $L \sim 4$. This might explain the lack of lightning generated whistlers observed in this same region of space. The coupling of EM whistler mode wave energy into LH waves beyond $L \sim 4$ may play a role in the dynamics of ring current protons through pitch angle scattering during gyroresonance and Landau resonance interactions.

Electron Foreshock: The first results of Langmuir wave observations in the electron foreshock using the WBD receiver on the four Cluster satellites have been presented by Sigsbee et al. [2004 in press].

Cluster data show for the first time that the centers of the probability distributions shift to lower amplitudes with increasing distance to the boundary, and that a spatially averaged power law distribution results from summing these distributions. Sigsbee et al. [2004 in press] also confirmed that the Langmuir wave amplitude probability distributions followed the log-normal statistics predicted by stochastic growth theory for all regions of the foreshock.

Tomography with IMAGE RPI and Cluster WBD: Initial theoretical studies of multi-spacecraft radio tomographic imaging of the magnetosphere have shown the potential scientific value of the technique. Cummer et al. [2003] report on the first experiments using the Radio Plasma Imager (RPI) on the IMAGE satellite as the transmitter and the WBD plasma wave receiver on the four Cluster satellites as the receiving instruments with propagation distances of approximately $3 R_E$. The series of 32 second signals from Image RPI with a 1 kHz frequency step between each step were cleanly picked up by all four Cluster WBD instruments. The experiments were focused specifically on measuring the plasma-induced rotation of the wave polarization (Faraday rotation), from which the path integrated product of magnetospheric electron density and magnetic field can be directly inferred. The analysis of Cummer et al. [2003] showed that this technique is powerful. By itself, Faraday rotation can only measure the $N_e B$ product. But in near Earth regions the known magnetic field enables electron density imaging which has scientific value in large scale measurements of the $N_e B$ product, particularly in evaluating the consistency of measurements and theoretical predictions of plasma structure and dynamics.

3.0 Publications

3.1 Statistics of Publications

During the period of this grant the Cluster WBD team has been very active in disseminating their research results through refereed publications. The following statistics detail how many refereed publications have been completed during the 3 years of the grant:

| | WBD Team Member First Author or WBD as Prime Data | WBD Team Member as a Contributing Author (Not First) |
|-----------|------------------------------------------------------|---------------------------------------------------------|
| Published | 9 | 3 |
| In Press | 6 | 2 |
| Submitted | 7 | 0 |

3.2 List of Publications during Reporting Period

A list of all of the publications that resulted from work carried out partially or wholly under the subject grant is as follows:

2001

D. A. Gurnett, R. L. Huff, J. S. Pickett, A. M. Persoon, R. L. Mutel, I. W. Christopher, C. A. Kletzing, U. S. Inan, W. M. Martin, J.-Bougeret, H. St. C. Alleyne, and K. H. Yearby, **First Results from the Cluster Wideband Plasma Wave Investigation**, *Annales Geophysicae*, 19, 1259-1271, Oct.-Dec. 2001.

P. M. E. Decreau, P. Ferreau, V. Krasnosels'kikh, E. LeGuirriec, M. Leveque, Ph. Martin, O. Randriamboarison, J. L. Rauch, F. X. Sene, H. C. Seran, J. G. Trotignon, P. Canu, N. Cornilleau-Wehrin, H. deFeraudy, H. St. C. Alleyne, K. H. Yearby, P. B. Mogensen, G. Gustafsson, M. Andre, D. A. Gurnett, and F. Darrouzet, **Early Results from the Whisper Instrument on Cluster: An Overview**, *Annales Geophysicae*, 19, 1241-1258, Oct.-Dec. 2001.

2002

O. Santolik, J. S. Pickett, D. A. Gurnett, M. Maksimovic, N. Cornilleau-Wehrin, **Spatiotemporal Variability and Propagation of Equatorial Noise Observed by Cluster**, *J. Geophys. Res.*, 107, No. A12, 1495, doi:10.1029/2001JA009159, Dec. 1, 2002.

S. M. Walker, M. A. Balikhin, I. Bates, and R. Huff, **An Investigation into Instrumental Nonlinear Effects**, *Adv. Space Res.*, 30, No. 12, pp. 2815-2820, 2002.

2003

J. S. Pickett, J. D. Menietti, D. A. Gurnett, B. Tsurutani, P. M. Kintner, E. Klatt, and A. Balogh, **Solitary Potential Structures Observed in the Magnetosheath by the Cluster Spacecraft**, *Nonlinear Processes in Geophys.*, 10, pp. 3-11, March 2003.

O. Santolik and D. A. Gurnett, **Transverse Dimensions of Chorus in the Source Region**, *Geophys. Res. Lett.*, 30, No. 2, 1031, doi:10.1029/2002GL016178, 2003.

O. Santolik, D. A. Gurnett, J. S. Pickett, M. Parrot, and N. Cornilleau-Wehrin, **Spatio-temporal Structure of Storm-Time Chorus**, *J. Geophys. Res.*, 108, No. A7, 1278, doi:10.1029/2002JA009791, July 9, 2003.

S. N. Walker, J. S. Pickett, D. A. Gurnett, and H. Alleyne, **High Order Spectral Analysis of Electron Plasma Oscillations in the Electron Foreshock**, *Adv. Space Res.*, 32, No. 3, 309-314, 2003. doi:10.1016/S0273-1177(03)00276-X.

S. A. Cummer, J. L. Green, B. W. Reinisch, S. F. Fung, M. L. Kaiser, J. S. Pickett, I. W. Christopher, R. L. Mutel, D. A. Gurnett, and C. P. Escoubet, **Advances in Magnetospheric Radio Wave Analysis and Tomography**, *Adv. Space Res.*, 32, No. 3, 329-336, 2003. doi:10.1016/S0273-1177(03)00270-9.

R. L. Mutel, D. A. Gurnett, I. W. Christopher, J. Pickett and M. Schlax, **Locations of Auroral Kilometric Radiation Bursts Inferred from Multi-Spacecraft Wideband Cluster VLBI Observations I: Description of Technique and Initial Results**, *J. Geophys. Res.*, 108, No. A11, 1398, Nov. 15, 2003. doi:10.1029/2003JA010011.

J. D. Menietti, R. R. Anderson, J. S. Pickett, D. A. Gurnett, and H. Matsumoto, **Near-Source and Remote Observations of Kilometric Continuum Radiation from Multi-Spacecraft Observations**, *J. Geophys. Res.*, 108, No. A11, 1393, Nov. 14, 2003. doi:10.1029/2003JA009826.

K. Stasiewicz, M. Longmore, S. Buchert, P. K. Shukla, B. Lavraud, and J. Pickett, **Properties of Fast Magnetosonic Shocklets at the Bow Shock**, *Geophys. Res. Lett.*, 30, No. 24, 2241, Dec. 17, 2003. doi:10.1029/2003GL017971.

Publications - In Press

O. Santolik, D.A. Gurnett, J.S. Pickett, M. Parrot, and N. Cornilleau-Wehrin, **A Microscopic and Nanoscopic View of Storm-Time Chorus on 31 March 2001**, *Geophys. Res. Lett.*, in press, 2004.

K. Sigsbee, C.A. Kletzing, D.A. Gurnett, J.S. Pickett, A. Balogh, and E. Lucek, **The Dependence of Langmuir Wave Amplitudes on Position in Earth's Foreshock**, *Geophys. Res. Lett.*, in press, 2004.

T. F. Bell, U. S. Inan, M. Platino, J. S. Pickett, P. A. Kossey, and E. J. Kennedy, **Cluster Observations of Lower Hybrid Waves Excited at High Altitudes by Electromagnetic Whistler Mode Signals from HAARP facility**, *Geophys. Res. Lett.*, in press, 2004.

M. Parrot, O. Santolik, D. A. Gurnett, J. S. Pickett, and N. Cornilleau-Wehrin, **Characteristic of Magnetospherically Reflected Chorus Waves Observed by Cluster**, *Annales Geophysicae*, in press, 2004.

U. S. Inan, M. Platino, T. F. Bell, D. A. Gurnett, and J. S. Pickett, **Cluster Measurements of Rapidly Moving Sources of ELF/VLF Chorus**, *J. Geophys. Res.*, in press, 2004.

V. Y. Trakhtengerts, A. G. Demekhov, E. E. Titova, B. V. Kozelov, O. Santolik, D. Gurnett, and M. Parrot, **Interpretation of Cluster Data on Chorus Emissions Using the Backward Wave Oscillator Model**, *Phys. Plasmas*, in press, 2004.

J. S. Pickett, S. W. Kahler, L.-J. Chen, R. L. Huff, O. Santolik, Y. Khotyaintsev, P. M. E. Decreau, D. Winningham, R. Frahm, M. L. Goldstein, G. S. Lakhina, B. T. Tsurutani, B. Lavraud, D. A. Gurnett, N. Cornilleau-Wehrin, M. Andre, A. Fazakerley, A. Balogh, and H. Reme, **Solitary Waves Observed in the Auroral Zone: The Cluster Multi-Spacecraft Perspective**, *Nonlinear Proc. in Geophys.*, in press, 2004.

O. Santolik, D. A. Gurnett, and J. S. Pickett, **Multipoint Investigation of the Source Region of Storm-Time Chorus**, *Annales Geophysicae*, in press, 2004.

Publications - Submitted

R. L. Mutel, D. A. Gurnett, I. W. Christopher, and M. Schlax, **Spatial and Temporal Properties of AKR Burst Emission Derived from Cluster WBD VLBI Studies**, *Annales Geophysicae*, in press, May 2004.

M. Platino, U. S. Inan, T. F. Bell, J. Pickett, E. J. Kennedy, J. G. Trotignon, J. L. Rauch, and P. Canu, **Cluster Observations of ELF/VLF Signals Generated by Modulated Heating of the Lower Ionosphere with the HAARP HF Transmitter**, *Annales Geophysicae*, in review, Dec. 2003.

J. S. Pickett, L.-J. Chen, S. W. Kahler, O. Santolik, D. A. Gurnett, B. T. Tsurutani, and A. Balogh, **Isolated Electrostatic Solitary Structures Observed Throughout the Cluster Orbit: Relationship to Magnetic Field Strength**, *Annales Geophysicae*, submitted, Oct. 2003.

A. Masson, U. S. Inan, H. Laakso, O. Santolik, and P. Decreau, **Cluster Observations of Banded Hiss Like Emissions Near the Plasmapause**, *Annales Geophysicae*, submitted, Oct. 2003.

K. Sigsbee, C. A. Kletzing, D. A. Gurnett, J. S. Pickett, A. Balogh, and E. Lucek, **Statistical Behavior of Foreshock Langmuir Waves Observed by the Cluster Wideband Data Plasma Wave Receiver**, *Annales Geophysicae*, submitted, Oct. 2003.

J. S. Pickett, O. Santolik, S. W. Kahler, A. Masson, M. L. Adrian, D. A. Gurnett, T. F. Bell, H. Laakso, M. Parrot, P. Decreau, A. Fazakerley, N. Cornilleau-Wehrin, A. Balogh, and M. Andre, **Multi-point Cluster Observations of VLF Risers, Fallers, and Hooks at and near the Plasmapause**, Proceedings, Interball/Cluster Conference on Magnetospheric Response to Solar Activity held in Prague, Czech Republic, September 2003, *NATO Science Series/Planetary Space Science*, submitted for publication, 2003.

O. Santolik, D. A. Gurnett, J. S. Pickett, M. Parrot, and N. Cornilleau-Wehrin, **Central Position of the Source Region of Storm-Time Chorus**, *Planet. Space Sci.*, submitted, Dec. 2003.

4.0 Public Outreach

A list of the public outreach activities carried out during the term of the subject grant in which the Cluster mission and Cluster science were discussed is as follows:

2000

University of Iowa Space Research, James R. Phillips, Franklin Elementary School, Marshalltown, Iowa, December 21, 1999. *Cluster, Cassini, Mars*

Laboratory tour and discussion about space physics, George Hospodarsky, Weber Elementary English as A Second Language Class, Iowa City, Iowa, Dec. 18, 2000. *Cassini, Cluster, Mars*

2001

Overview of Spaceflight Hardware Built by University of Iowa Plasma Wave Group, Donald Kirchner, Central Lee High School, Donnellson, Iowa, April 4, 2001. *Voyager, Galileo, Cluster, Cassini*,

Mars Express

Life as a Space Scientist at the University of Iowa, George Hospodarsky, presented to Grades 3 and 4, Solon Elementary School, Solon, Iowa, April 26, 2001. *Galileo, Polar, Cassini, Cluster*

Life as a Space Scientist, George Hospodarsky, Northwest Jr. High School, Coralville, Iowa, May 10, 2001. *Galileo, Polar, Cassini, Cluster*

Tour of U. of Iowa Space Physics Laboratories, George Hospodarsky, Northwest Jr. High School, Iowa City, Iowa, May 22, 2001. *Voyager, Galileo, Polar, Cassini, Cluster, Mars Express*

Space: Past, Present, and Future; Iowa Space Pioneers, Overview of University of Iowa's role in space physics research, Coordinated by Kathy Kurth, Cherokee, Iowa, Jan. 4, 2001 - June 18, 2001. *Explorer, Hawkeye, Injun, ISEE, Helios, Voyager, PDP, Galileo, Polar, Cassini, Cluster, Geotail. Exhibit information*

ACE (Ambassadors Connecting with Engineers) Academy Summer School, Michael Mitchell, Iowa City, Iowa, June 20, 2001. *Mars, Cluster, Galileo, Cassini*

Summary of Space Physics at University of Iowa, George Hospodarsky, Prospective Student Tour, Iowa City, Iowa, July 25, 2001. *Polar, Galileo, Cassini, Cluster, Mars, Voyager*

Summary of U. of Iowa's Participation in Experimental Space Research, George Hospodarsky, Korean Teacher's Workshop, Iowa City, Iowa, Aug. 17, 2001. *Voyager, Galileo, Polar, Cassini, Cluster, Mars*

AGU Press Conference, Robert L. Mutel, Presentation entitled "Direct Detection of AKR Source Locations Using Cluster WBD Differential Delay Measurements", Fall AGU Meeting, San Francisco, California, December 14, 2001. *Cluster*

2002

Space Research at the University of Iowa, Donald Gurnett, Iowa Senate Education Committee, Des Moines, Iowa, Jan. 28, 2002. *Voyager, Galileo, Cassini, Wind, Polar, Cluster, Mars*

Summary of UI's Participation in Space Research, George Hospodarsky, Tour for Prospective Graduate Students, Iowa City, Iowa, Feb. 1, 2002. *Voyager, Galileo, Cassini, Cluster, Polar, Mars*

Space Research at the University of Iowa, George Hospodarsky, Burlington Kiwanis Club, Burlington, Iowa, Feb. 21, 2002. *Explorer, Hawkeye, Voyager, Galileo, Cassini, Cluster, Polar, Mars*

University of Iowa's Role in Space Physics Research, Terry Averkamp, U. of Iowa (ACE) Ambassadors Connecting with Engineering Academy, Iowa City, Iowa, June 19, 2002. *Explorer, Hawkeye, Voyager, Galileo, Cassini, Cluster*

University of Iowa Space Research, George Hospodarsky, QuarkNet Classes for Physics Teachers, Iowa City, Iowa, July 3, 2002. *Cassini, Cluster, Galileo, Voyager*

Sights and Sounds of Space Physics, William Kurth, George Hospodarsky, Kathy Kurth, Iowa State Fair University of Iowa Exhibit Booth, Des Moines, Iowa, August 13, 2002. *Cassini, Cluster, Galileo, Voyager, Polar*. Summary and photos

The Songs of the Aurora and the Solar Wind, William Kurth, Family Adventures in Science, University of Iowa, Iowa City, Iowa, October 19, 2002. (*Voyager, Galileo, Cassini, Cluster, Polar*)

Sounds of Space and the Kronos Quartet Sun Rings: A Pre-Performance Presentation, Donald A. Gurnett, David Harrington, Terry Riley, and Willie Williams, University of Iowa, Iowa City, Iowa, October 24, 2002. (*Voyager, Galileo, Cassini, Cluster, Polar*)

Sounds of Space and the Kronos Quartet Sun Rings: A Pre-Performance Discussion, Donald A. Gurnett, Terry Riley, David Dvorin, Greenroom, Hancher Auditorium, Iowa City, Iowa, October 26, 2002. (*Voyager, Galileo, Cassini, Cluster, Polar*)

Sun Rings, Kronos Quartet, Hancher Auditorium, Iowa City, Iowa, October 26, 2002. Production based on the sounds of space collected by Prof. D. Gurnett over a 30-year period, commissioned by the NASA Arts Program office and supported by the Hancher Rubright Memorial. (*Voyager, Galileo, Cassini, Polar, Cluster*)

Space Physics Research at the University of Iowa, George Hospodarsky, Solon 6th Grade Class (96 students), Solon, Iowa, November 8, 2002. (*Sounds of space, Cassini, Voyager, Galileo, Cluster, Polar*)

Recent University of Iowa Experimental Space Research Projects and a Tour of the Spaceflight Fabrication Labs., William Robison, Iowa City Amateur Radio Club, Iowa City, Iowa, November 13, 2002. (*Polar, Cluster, Cassini, Mars Express*)

Sounds of Plasma Waves In Space, William Kurth, Coralville Central 4th Grade Class (25 students), Coralville, Iowa, November 25, 2002. (*Galileo, Cassini, Voyager, Polar, Cluster*)

2003

Sounds of Space and the Kronos Quartet Sun Rings, A Pre-Performance Presentation, Bert Ulrich, Donald A. Gurnett, and David Harrington, University of Houston Clear Lake Theater (200 people), Houston, Texas, January 22, 2003. (*Voyager, Galileo, Cassini, Cluster, Polar*)

Sun Rings, Kronos Quartet, Wortham Center's Cullen Theater, Houston, Texas, January 23, 2003. Production based on the sounds of space collected by Prof. D. Gurnett over a 40-year period, commissioned by the NASA Arts Program office and co-commissioned by the Hancher Auditorium, the University of Iowa, the National Endowment for the Arts, the Rockefeller Foundation, the Society of Performing Arts, the University of Houston Clear Lake, and other music-presenting organizations. (*Voyager, Galileo, Cassini, Polar, Cluster*)

Space Research at the University of Iowa, George Hospodarsky, Iowa City Elementary Students toured the Dept. of Physics and Astronomy space physics laboratories, February 7, 2003. (*Voyager, Galileo, Cassini, Polar, Cluster, Mars Express*)

Our Solar System, George Hospodarsky, Lincoln Elementary Kindergarten Class (35 students), Iowa City, Iowa, March 12, 2003. (*Cassini, Voyager, Galileo, Cluster*)

Sounds of Space and the Kronos Quartet *Sun Rings*, A Pre-Concert Presentation, Donald A. Gurnett and Willie Williams, Barbican Centre (600 people), London, United Kingdom, March 22, 2003. (*Voyager, Galileo, Cassini, Cluster, Polar*)

Sun Rings, Kronos Quartet, Barbican Centre, London, United Kingdom, March 22, 2003. Production based on the sounds of space collected by Prof. D. Gurnett over a 40-year period, commissioned by the NASA Arts Program office and co-commissioned by the Hancher Auditorium, the University of Iowa, the National Endowment for the Arts, the Rockefeller Foundation, the Society of Performing Arts, Barbican Centre/London, and other music-presenting organizations. (*Voyager, Galileo, Cassini, Polar, Cluster*)

Life as a Space Scientist, George Hospodarsky, Van Buren Elementary Career Day for Grades K-6 (120 students), Cedar Rapids, Iowa, April 30, 2003. (*Sounds of space, Cassini, Voyager, Galileo, Cluster, Polar, Mars Express*)

University of Iowa Space Research: Past, Present, and Future, George Hospodarsky, Whittier Elementary School Space Day, Grades K-6 (125 students/parents), Clinton, Iowa, May 2, 2003. (*Sounds of space, Cassini, Voyager, Galileo, Cluster, Polar*)

A Typical Day in the Life as of a Space Scientist, George Hospodarsky, Northwest Junior High School (120 students), Coralville, Iowa, May 28, 2003. (*Discussed education requirements, job responsibilities; discussed current University of Iowa projects: Cassini, Voyager, Galileo, Cluster, Polar, Mars Express*)

University of Iowa Space Research, George Hospodarsky, William Kurth, William Robison, Ondrej Santolik, Jean Hospodarsky, and Kathy Kurth, Fly Iowa 2003 (~500 people), Eastern Iowa Airport, Cedar Rapids, Iowa, July 5-6, 2003. (*Included Cluster mission information, a Cluster Wideband electronics unit, and sounds from Cluster Wideband data*). Photos

Sounds of Space and the Kronos Quartet *Sun Rings*, A Pre-Performance Presentation, Donald A. Gurnett, public lecture at the Westin South Coast Plaza (100 people), Costa Mesa, California, October 12, 2003. (*Voyager, Galileo, Cassini, Cluster, Polar*)

Exploring Space, George Hospodarsky, public lecture for youth at the Orange County Performing Arts Center (60 people), Costa Mesa, California, October 12, 2003. (*Voyager, Galileo, Cassini, Cluster, Polar, Mars*)

Sounds of Space and the Kronos Quartet *Sun Rings*, A Pre-Concert Presentation, Donald A. Gurnett and Terry Riley, public lecture at the Orange County Performing Arts Center (2000 people), Costa Mesa, California, October 14, 2003. (*Voyager, Galileo, Cassini, Cluster, Polar*)

Sun Rings, Kronos Quartet, Orange County Performing Arts Center, Costa Mesa, California, October 14, 2003.

Production based on the sounds of space collected by Prof. D. Gurnett over a 40-year period, commissioned by the NASA Arts Program office and co-commissioned by the Hancher Auditorium, the University of Iowa, the National Endowment for the Arts, the Rockefeller Foundation, the Society of Performing Arts, the University of Houston Clear Lake, and other music-presenting organizations.

(Voyager, Galileo, Cassini, Polar, Cluster)

Why Study Space?, George Hospodarsky, Cub Scouts (50 scouts and parents), Iowa City, Iowa, Nov. 11, 2003. *(Voyager, Galileo, Cassini, Polar, Cluster, Mars, sounds of space)*

What You Can Learn From Studying Space, George Hospodarsky, Solon Elementary 6th Grade Class (93 students), Solon, Iowa, Nov. 14, 2003. *(Voyager, Galileo, Cassini, Polar, Cluster, Mars, sounds of space)*